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GRANULATION IN AND OUT OF MAGNETIC REGION

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ABSTRACT: We performed an analysis of several granulation pictures obtained in both a quiet region and a plage or magnetic region. Filtergrams of ultra–narrow passband and free of line–blocking were obtained with the Sac Peak Vacuum Telescope with an average 0.5 arcsec spatial resolution. Results of a statistical comparative study are presented: amplitude spectra, RMS and histograms of intensity fluctuations. The precise location of a large sample of magnetic field structures identified with MgI b_1 + 0.4A filtergrams was analyzed; 20.4% of these structures overlap or are inserted in granules, which gives a natural explanation of the high value of the RMS in the magnetic region. We used selected very high spatial resolution broad–band short exposure time pictures to show crinkles–type structures at the center of granules that we identify with the abnormal granulation and "magnetic" granules.

I. INTRODUCTION

Since the discovery by Dunn and Zirker, 1973, of solar filigrees, many attempts have been made to explain the high contrast of facular and network structures observed in the continuum by Mehltretter, 1974, Koutchmy, 1977 and Muller and Keil, 1983, at the center of the Solar disc or at optical depth near unity. Moreover a well–established correlation between these structures and the concentration of magnetic flux as detected in photospheric lines (10^{-1} to 10^{-3} optical depths) exists, see, e.g. Dunn et al. 1974. When the granulation in magnetic regions is considered, a large confusion seems to emerge from an inspection of the literature. Although the term "abnormal granulation" has been introduced, beginning with the first paper of Dunn and Zirker, 1973 few authors indeed have analyzed the behaviour of granulation in a magnetic region, preferring to "forget" that filigrees in form of "crinkles" interact with granules, as clearly stated, e.g., by Mehltretter, 1974. This last author did not however identify the phenomena with the facular granules analyzed later on by Muller, 1977. Further, Muller, 1983 claimed that facular structures (presumably filigree structures) at the disk center are made of points and, additionally, that these "facular points" occur <u>only</u> between granules.

High resolution pictures from Sac Peak Observatory show clearly filigree structures not only inserted between granules, but also structures well connected with granules ("overlapping" them), see figure 1 and even, more rarely, at the center of granules! Obviously, it is far more easy to see a very small bright "crinkle" over the dark intergranular lanes background than over a bright granules, so the analysis of these structures is greatly biased by the inability of the best instruments, (not to mention the seeing effects) to correctly

R. J. Rutten and G. Severino (eds.), Solar and Stellar Granulation, 253–271.

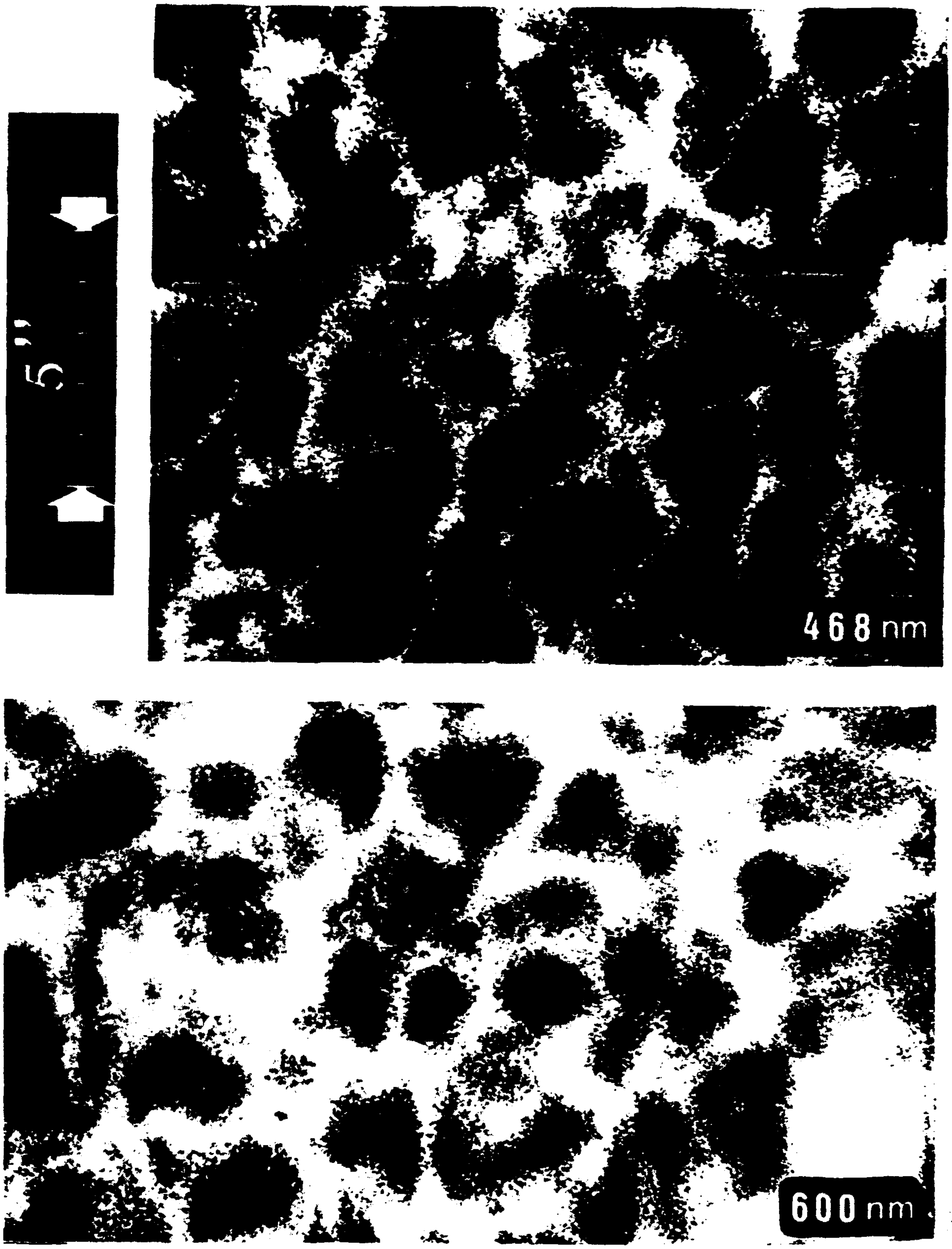

Figure 1. Typical filigree structure observed at 468nm with a passband of 3.5nm (line–blocking effect 11%) and at 600nm with 6nm passband (ℓ–blocking 4%), and a 5msec exposure time, at the prime focus of the SP/VTT (original scale 3.75 arcsec/mm on Kodak microfilm 5460). Note the morphology of the "crinkle" structures suggesting that at least a part of them is overlapping the edge of an "abnormal" granule.

transfer the intensity modulations corresponding to these very small features. Fortunately, magnetic structures can be easily identified in photospheric lines or wings of strong lines, so filtergrams can be used. The granulation is observed at the best in the continuum, avoiding line blocking effects; then very narrow band filtergrams are required. From the theoretical point of view, models of flux tubes have been promoted to explain observations. There again a confusion exists, as different authors use different, sometimes incompatible, approaches. The popular "hot-walls" effect, Spruit 1976, is still competing with the "hot-cloud" model, Rogerson, 1961 and Chapman, 1970, to explain line profiles and center-limb contrasts. However, apparently no arguments have been brought in favor or against the interaction and even the co-existence of a magnetic element and of a granule...The Nordlund (1983) numerical simulations suggest a relation between the concentrationof magnetic field and the downdraft velocities (which are observed typically in intergranular lanes). However, both high spatial resolution spectroscopic observations (Koutchmy and Stellmacher, 1978) and V-Stokes precise profile measurements (Stenflo et al. 1987) agree in showing that no large downdrafts are present in flux tube regions; moreover, the 5-min. oscillations are present, see Dara et al. 1987, making the interpretation of instantaneous observations of velocities rather delicate (saying nothing, again, of problems produced by seeing effects). Finally, let us notice that since downdrafts being systematically observed in intergranular lanes and filigrees observed only in few special locations, at least one additional condition for the "production" of flux tubes should exist, even if the connection downdraft/magnetic structure exists. Here, we will leave this question open and will rather concentrate on the question of "co-spatiallity" of the magnetic field region and the granulation field, as evidenced by the comparison of different filtergrams. This question was also addressed in the recent paper of Title et al. 1987, also performed using the Sac Peak Vacuum Tower Telescope (SP-VTT) with a slightly different technique. Additionally, this latest work gives a comprehensive presentation of the "abnormal granulation" phenomenon; the main conclusion of these authors is that the magnetic field structures map a larger area than just the filigree and especially the "bright-point" locations, a conclusion in agreement with the early finding of Simon and Zirker, 1974, in a plage region and of Koutchmy and Stellmacher, 1978, in a quiet network region.

II. OVERVIEW OF THE METHODS USED AND APPLICATIONS

It is well known that magnetic structures are difficult to map at very high spatial resolution because the signal to noise ratio is rather low and integration is required; then, the spatial resolution is lost due to the variation of image quality, especially image motions and distortion. On the other hand, frame selection of short exposure time pictures is a very effective method, as it has been demonstrated in the Rosch's and Muller's analysis of the Pic du Midi observations. At the SP-VTT, using frame selection, it is also possible to obtain diffraction limited pictures, provided a sufficiently short exposure time is used (recent measurements performed by P. Brandt at the SP-VTT confirmed that moments of seeing quality with r_0 at least equal to the radius of the entrance effective aperture of 76 cm are not infrequent). So, we decided to use this method applied to sequences of filtergrams made with the UBF of the SP-VTT, see e.g. Beckers, 1976, in order to preserve the best possible spatial resolution. However, to map the magnetic structures, we used their thermodynamic properties, namely the greatly enhanced temperature in these regions, at heights of photospheric line formation. Further, instead of making the difficult choice of the best suited line, we decided to use the line which is best suited for UBF observations, with its limited spectral range and its limited spectral resolution. Figure 2 shows the computed profile of the b_2–line of MgI (the b_1 line of MgI shows almost exactly the same behaviour) obtained by G. Stellmacher from the model of Koutchmy and Stellmacher, 1978 shown on Figure 3. This last figure compares different models of magnetic field structures. The temperature effect is always present at the heights of formation of the wing of the b_1 line of MgI and we found, following Beckers 1976, that the positions at plus or minus 0.4A from the line center give a good contrast for magnetic structures, as it is clear also from the inspection of Figure 2 (see also Dara and Koutchmy, 1983). Let us notice, however, that although a general agreement exists concerning the temperature effects at these heights (roughly $\tau_5 = 10^{-3}$), it is not yet clear if the magnetic field is concentrated in the tiny crinkles only or not. Figure 4 shows the distribution, at high spatial resolution, of the I and the V–Stokes parameter over a magnetic structure. It demonstrates again that at the continuum level, no peculiar brightening is observed, suggesting that at this level the magnetic structure is more extended than just the tiny crinkles (not resolved, evidently, on the spectrum). This deduction does not take into account the possible effect of a large constriction of the magnetic field in the low photosphere.

III OBSERVATIONS

All reported observations were made with the SP–VTT during moments of superb seeing. Our spectroscopic observations were already reported in several papers, see e.g. Koutchmy and Stellmacher, 1978 and Dara et al. 1987. Figure 4 illustrates what can be extracted from these sequences. The results motivated the new observations performed with the UBF in order to cover simultaneously a large magnetic region. Figure 5 shows the whole region observed, around a small sunspot, as well as the two selected regions where a photometric analysis was performed with the fast microphotometer of SPO. The sequence selected is made of four pictures taken in the true continuum of the blue, green and red parts of the solar spectrum, see Table I. These selected pictures are separated by a time interval not exceeding 5 sec of time. The exposure time was chosen to give an optimum photographic density (nearly 2) for the photosphere; however, umbral dots are well exposed in the core of the sunspot on the continuum pictures, confirming their high quality. The wavelength in each spectral region has been carefully chosen, after the inspection of several solar spectrum atlases and, also, the J. Harvey sunspot spectrum atlas. The calibration has been made with an out of focus Sun and a specially designed space–qualified sensitometer with 36 neutral steps. Flat fields were also photographed to take into account the noise of the very fine grain and the vignetting of the optical system. Matrices of 256 x 256 points were recorded with a sample interval equivalent to .128 arcsec with a .35 arcsec FWHM gaussian pin–hole. Figure 6 shows the reproduced from the video display matrices of both the quiet photosphere and the plage region in true continuum emission of different spectral regions.
Finally, observations were also made with broad bands, see Table 1, in order to have very short exposure times and a great number of pictures with a good scale for

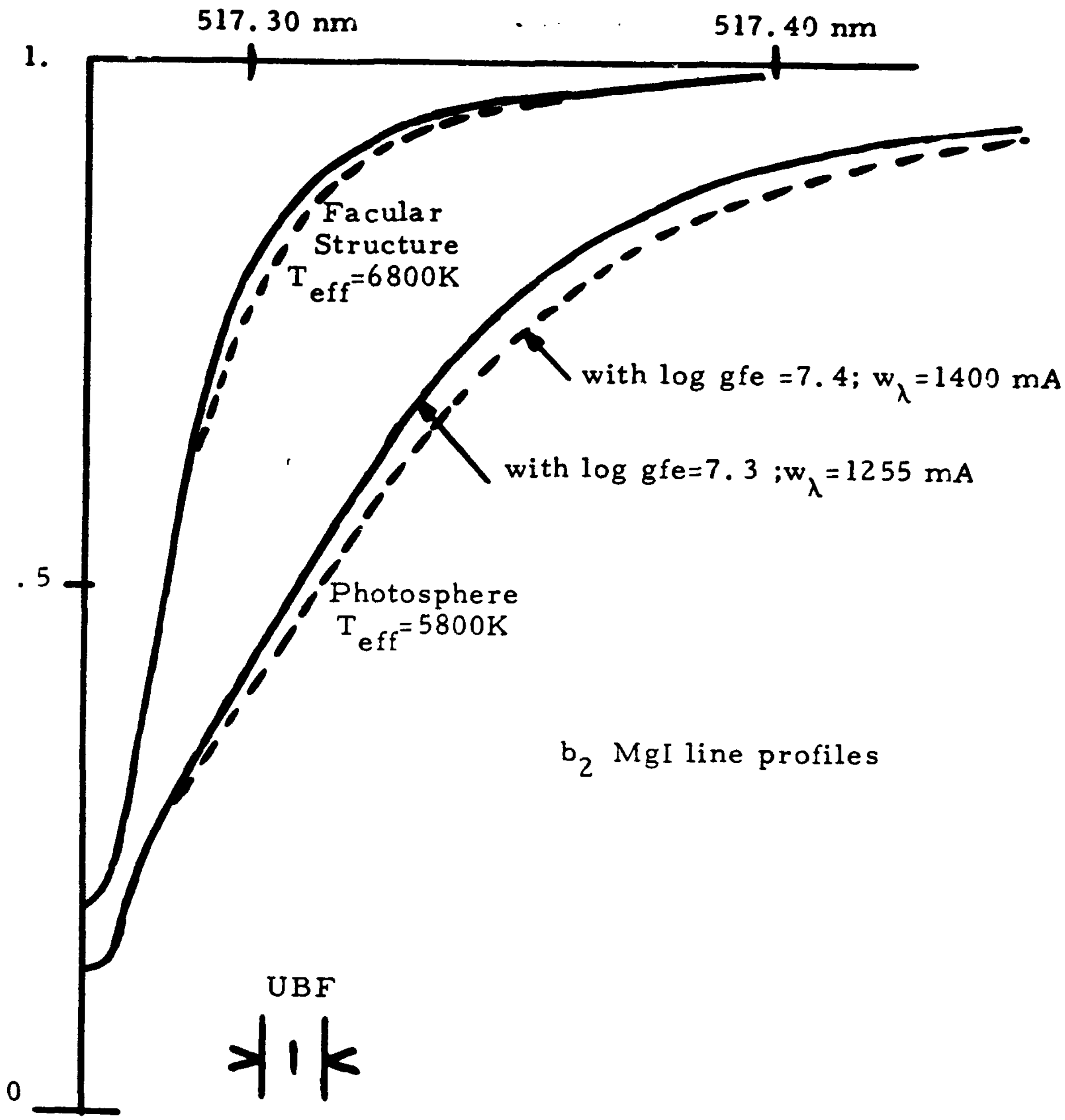

Figure 2. Profile of the Mg b_2 line, calculated for the homogeneous photosphere and for a bright element of a magnetic field structure with the model of Koutchmy and Stellmacher, 1978. The position of the UBF passband used to make filtergrams showing the magnetic structure is indicated.

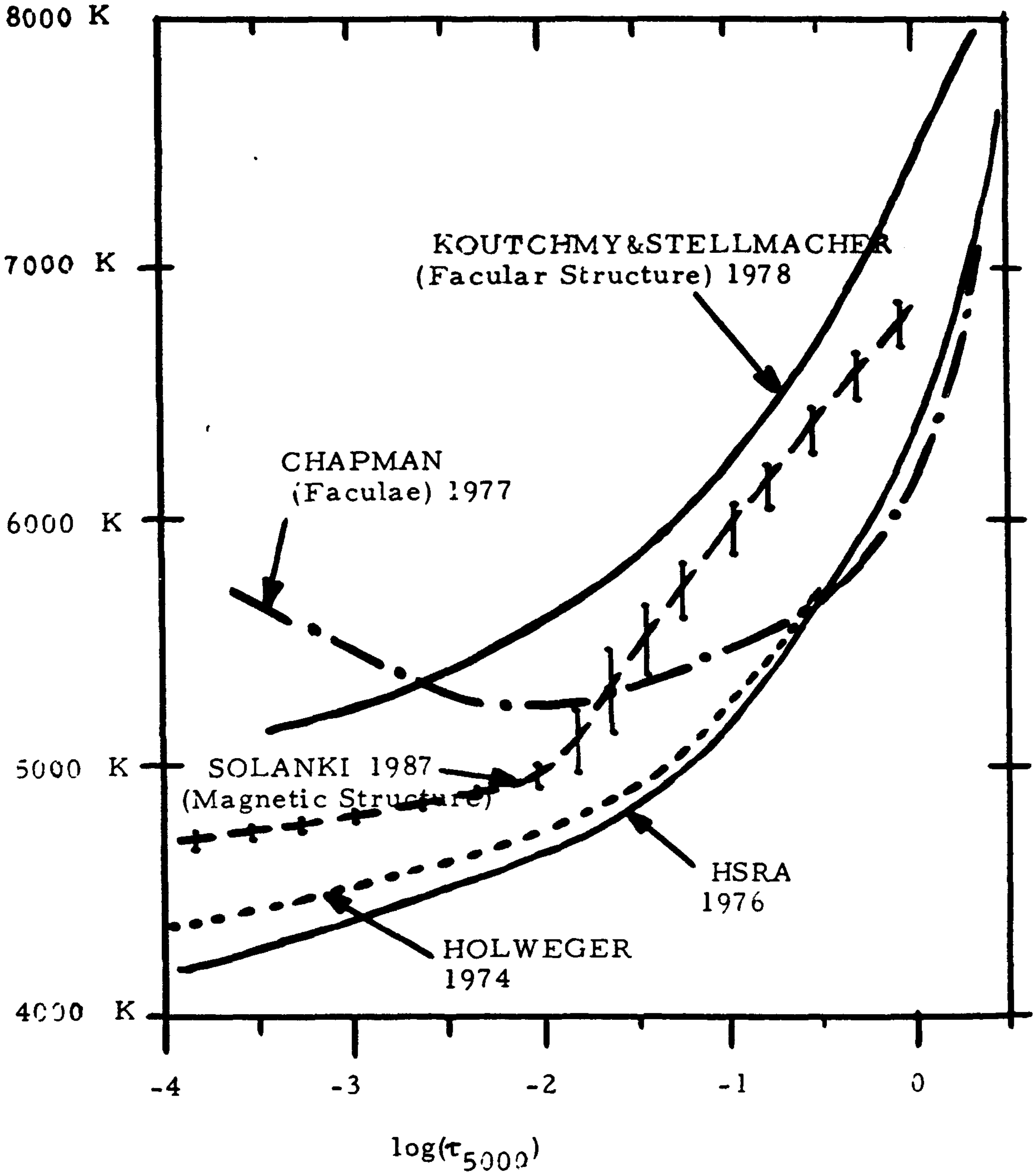

Figure 8. Different temperature models of photospheric atmospheres. Note that the model of Koutchmy and Stellmacher, 1978, corresponds to the hot component alone of the magnetic structure which is more extended than just the bright structure. The Chapman's model does not reproduce observations of a bright structure at the low photospheric level; the Solanki's model is based on the interpretation of the V–Stokes whole profile of several photospheric magnetic lines in magnetic regions; it incorporates a partially physical model of flux tubes.

Table 1 Parameters of the Analyzed Observations (VTT/SPO)

Spectral Region	Wavelength λo (nm)	FWHM(nm)or dispersion	τ (Sec)	Film Type (Kodak)	Contrast	Resolution	Scale (arcsec/mm)
B	445.1240	0.009	0.5	2415	γ = 3.6	0".6	10
V	525.635	0.013	0.1	2415	γ = 3.8	0".5	10
R	606.960	0.018	0.1	2415	γ = 3.8	0".4	10
Mgb_1 +0.4	518.405	0.012	0.3	2415	γ = 3.8	0".5	10
W.L.	4680	3.5	0.004	5460	γ = 3.5	0"17	3.75
W.L.	6000	6	0.004	5460	γ = 3.6	0"21	3.75
Spectra	6302.5	8mm/0.1nm	1.5sec	50392	γ = 3.6	0"7	3.75

Figure 4. One–dimensional distribution of the I and of the V–Stokes parameters observed around a magnetic element of the chromospheric network in the 630.25nm line of FeI (Landé factor: 2.5). A typical 1 KG magnetic field is observed directly (splitting) over an area of 1.5 to 2 arcsec, showing no prominent brightening (nor darkening) on the continuum.

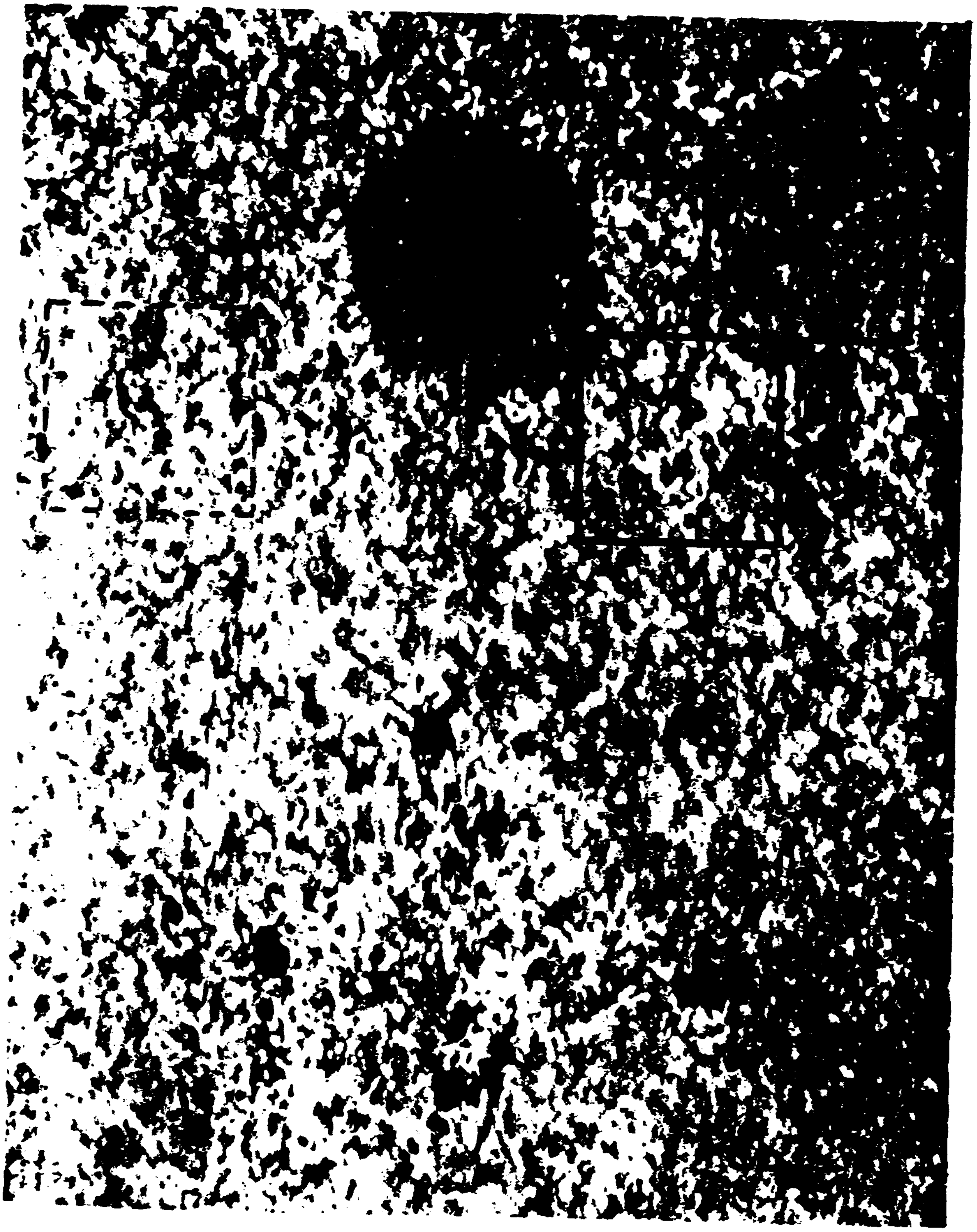

Figure 5. Print of a large portion of the original field of view selected for the study of the granulation in and out of the magnetic regions. The drawn squares represent the region selected for the microphotometric analysis. Their size is 32.6 x 32.6 arcsec^2.

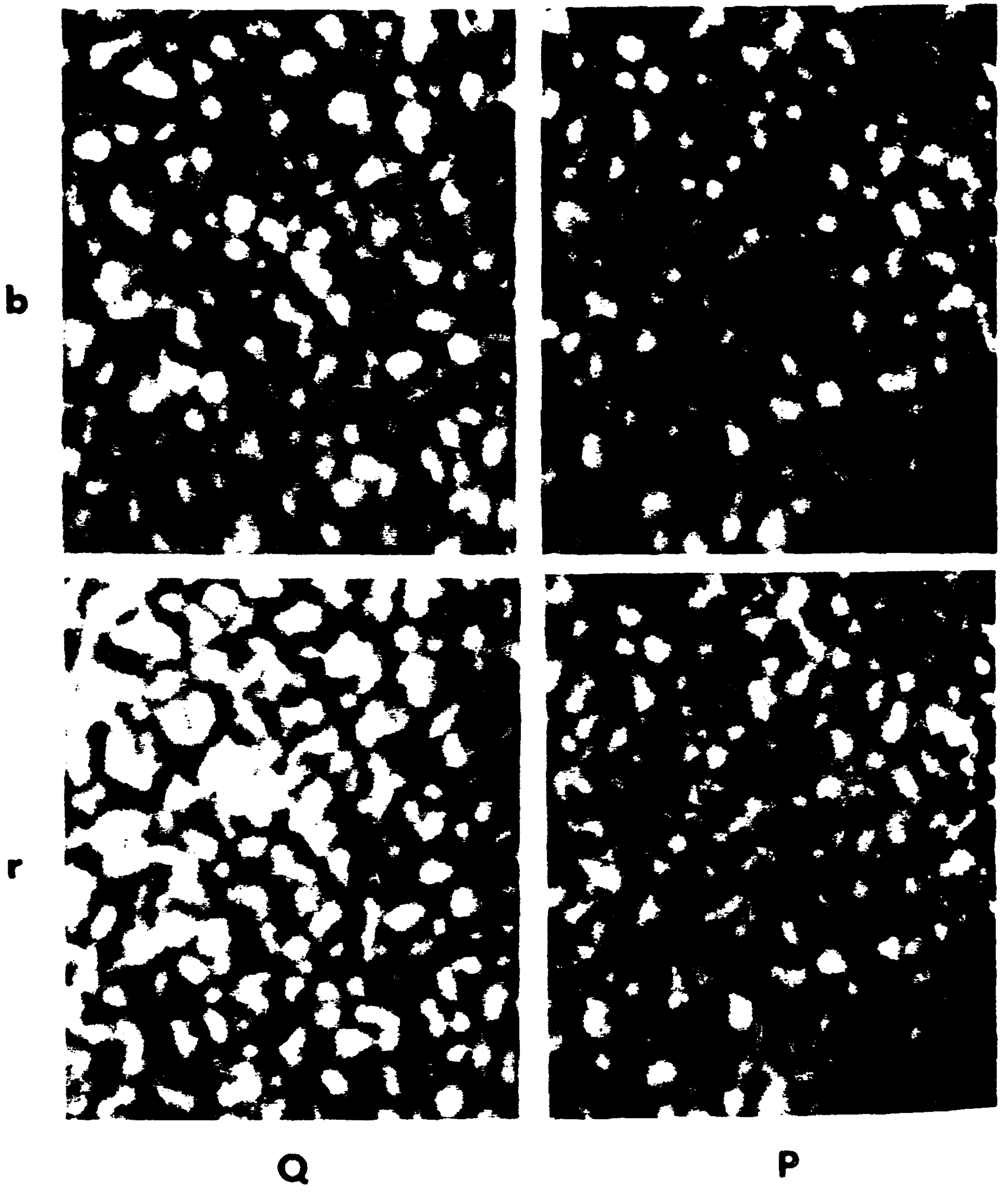

Figure 6. Reproduction from the video–display of the recorded fields of the quiet region (Q) and of the plage region (P), after calibration and removal of the vignetting effect. Note the slight difference in image quality from the blue (b) to the red (r) and the appearance of the "abnormal" granulation.

reducing the noise due to the photographic grain. Figure 1 give a sample of these pictures, showing a very small part of the photographed field of view. Thousands of photographic pictures are available for the analysis; some of them were selected to make a movie. We also tried, without success, to use different video CCD cameras. Results on very fine grain film are still the best.

IV. ANALYSIS, RESULTS AND DISCUSSIONS

a. The results of the statistical analysis of the intensity modulations measured on the filtergrams taken in the true continuum are shown in Table 2 and Figure 7, which represent only a sample of the results. Surprisingly, the RMS of intensity fluctuation of the plage region is found higher than the RMS of the quiet photosphere. This result could be especially convincing if we take into account the fact that the "blue" pictures show the best contrast, although the "red" pictures show the best resolution as expected from the consideration of exposure time and seeing effects. It needs confirmation.
Figure 7 compares the radial amplitude spectra (square root of the 2 dimensional power spectra per interval of frequency) observed on the "red" pictures (after removing the effect of the noise); no attempt is made to remove the instrumental attenuation of the spectral distribution, see Koutchmy 1977. However, it seems that more spectral power is present in the high frequency part of the spectrum, a result which is well understood in term of small scale fluctuations produce by the influence of filigrees.

Table II. Values of the RMS of intensity variations observed over the recorded pictures in different windows of the true continuum of the solar spectrum (after removal of the DC component row per row, in 2 directions).

Spectral Regions (nm)	RMS (±%) Quiet Region	RMS (±%) Plage Region
445.1240	7.02	7.48
525.635	6.73	6.74
606.960	5.37	5.86

This result is partially substantiated by the analysis of histograms of intensity fluctuations, showing a definite difference, when the two regions are compared. On the plage (magnetic) region, histograms are more extended; addionally more "bright" pixels are observed and less "dark" ones, for intensities around the average.
Further,using the properly calibrated intensity matrices in different colors, a color index mapping was attempted. Up to now, mixed success was obtained because the differential distortion effect on pictures produces a rather important noise. Only a part of the fields shown on figure 5 and 6 can be properly cross–correlated. A destretching program could be tried also. Preliminary results indicate few new features seems to appear: the map of color

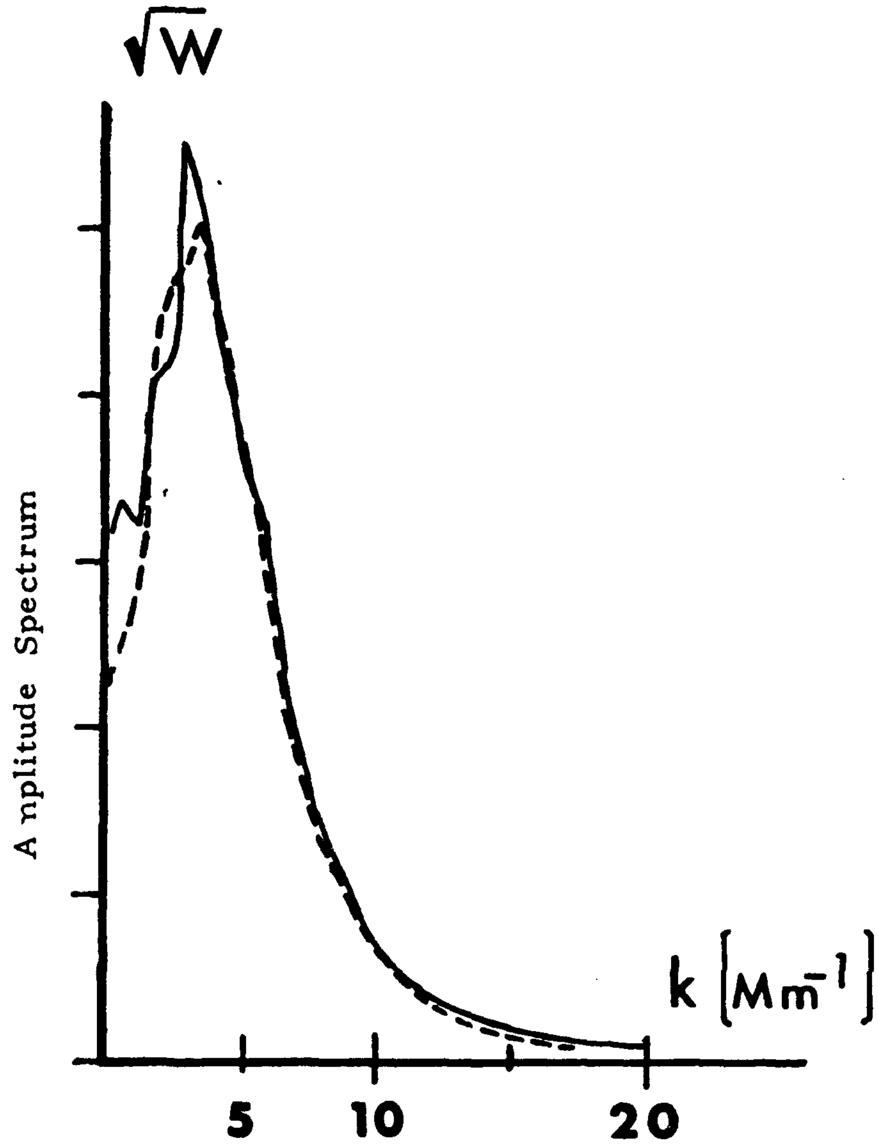

Figure 7. Amplitude radial spectra obtained from the study of the intensity fluctuations (at 606.95nm over the quiet photosphere (dashed line) and the plage region (full line). Note that the plage (or magnetic) region gives slightly higher amplitudes in the high frequency part of the spectrum.

index distribution (ratio of intensities of different color) is showing structures definitely different from just the 2D–intensity distribution over the field.

b. Further, we looked at the locations of magnetic field structures, as deduced from our best MgI b_1 + 0.4A filtergram, with respect to the location of granules and intergranular lanes. Figure 8 shows the distribution of magnetic field structures outside the sunspot and outside the pores (which are well seen on the continuum pictures. We chose to sample the bright elements at 0"77 arcsec intervals and 1244 elements were identified over the whole field. Furthermore, a count was made of magnetic elements per unit area. We took as a unit area 60 arcsec^2, so 207 areas were analyzed (48% of the overall surface of the field). The distribution function of the number of magnetic elements per unit area is shown on Figure 9. Finally, a careful identification of magnetic elements location was made by superposing the map shown on Figure 8 on the continuum pictures. In order to reduce the noise in making the identification, we considered only cases when the magnetic element is located "well" inside a bright granule (we did not count cases when the magnetic element is near the edge of the granule or evidently, when it is in darkintergranular lane). The result of this analysis is shown on figure 10; it shows maximum well displaced with respect to the position of the maximum on figure 9. We first notice that the total number of magnetic elements inside a granule (254) represents 20.4% of the total number of identified magnetic elements over the picture. The density distibution of the magnetic elements (Figure 9) seems to sugget that an "optimum" density exists; more importantly, when only magnetic elements located in a granule are considered, (Figure 10) an "optimum" density of magnetic elements exists which corresponds to maximum occurence of magnetic elements located in a granule.

V. CONCLUSIONS

Taking into account the results presented in part 4, we conclude:

a. abnormal granulation (granulation in plage region) does not show an RMS of intensity fluctuations smaller than in the normal granulation, as it was expected if bright filigree features were only "filling" the intergranular space. Evidence was shown for the reverse.

b. Amplitude spectrum, color index and histogram analysis made in different spectral regions of the true continuum suggest complex relations which need further investigations.

c. A visual correlation analysis of the location of magnetic elements, performed over a statistically significant number of elements, show convincingly that 20.4% of magnetic elements are located in a granule and, additionally, these "magnetic granules" are more numerous for a high enough number of magnetic elements per unit area; they should be also brighter.

d. We did not try in this study to deduce any value for the strength of the magnetic field structures. We, however, noticed a slight tendancy for magnetic elements located in a granule to be less bright in MgIb_1 + 0.4, which could mean a smaller amplitude of B in the high photosphere. The existence of a moderate strength magnetic field component in magnetic structures is still an open question, see Semel, 1986, so no

Figure 8. Location of magnetic field structures obtained from the visual inspection of the best MgI b_1 + 0.4 filtergram. Locations of the sunspot and of the pores are also indicated. Magnetic elements were sampled by hand over a greatly magnified print, using a threshold of local brightness.

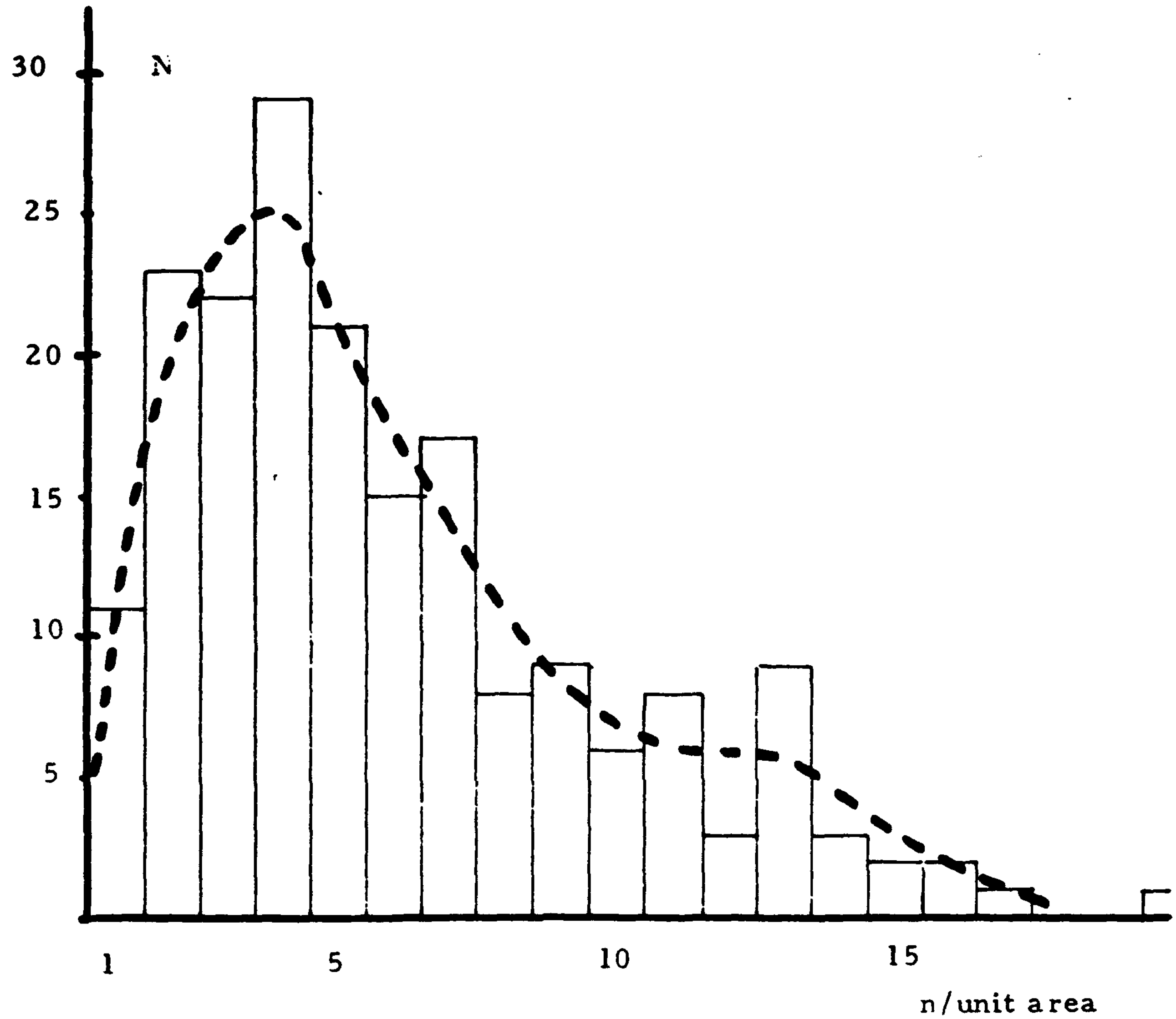

Figure 9. Distribution function (deduced from the histogram) of the number of magnetic elements per unit area. 1244 elements were taken into account; the unit area is 60 arcsec^2 and the sample "length" of each magnetic elements is 0.77 arcsec.

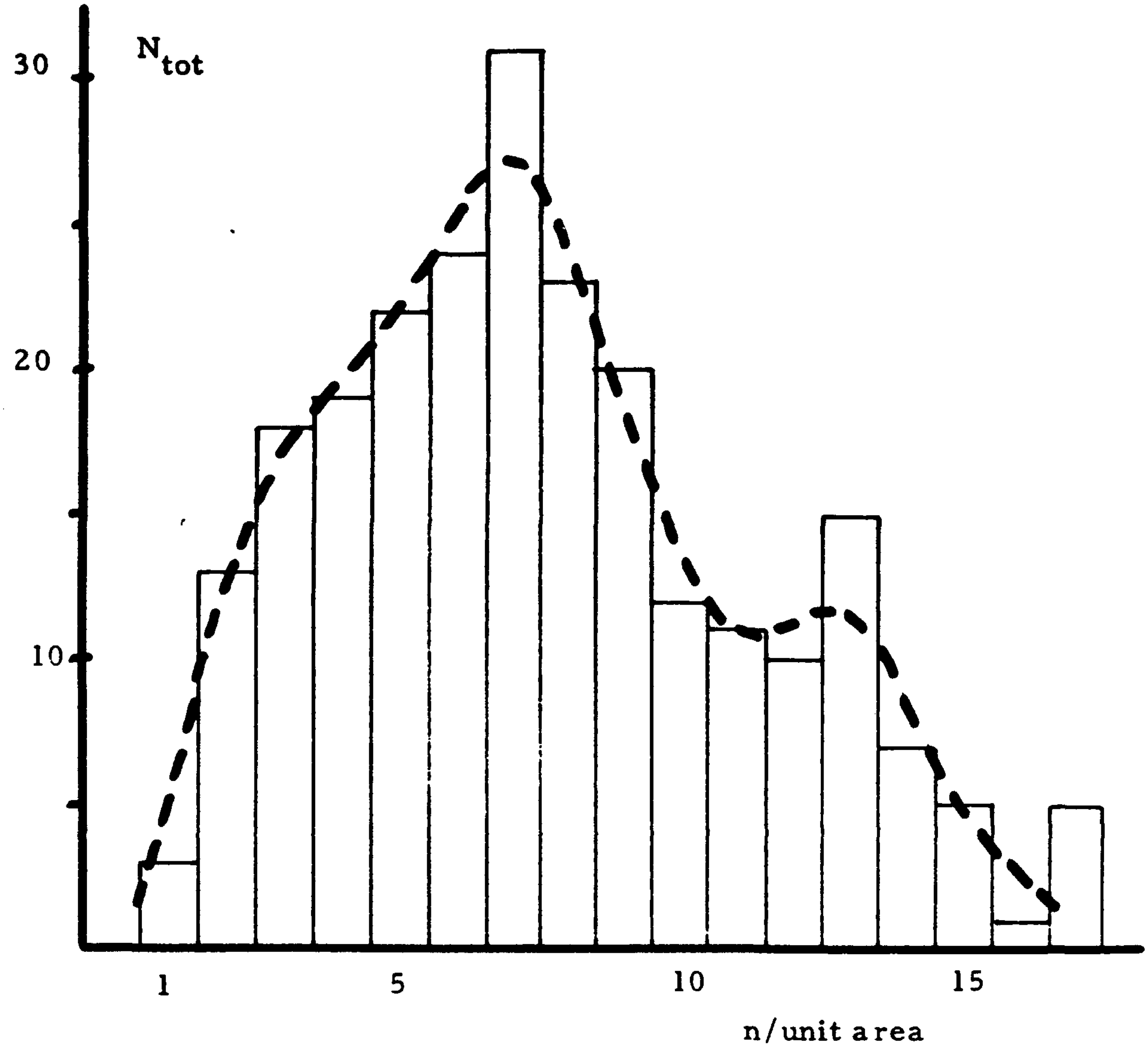

Figure 10. Distribution function of the total number of magnetic elements located in granules as a function of the number of magnetic elements per unit area.

definite conclusions can be made.

e. The picture of abnormal granulation coming from this analysis should be incorporated in a dynamical context. Taking a typical life–time of a granule 7 m in, our statistical analysis implied that magnetic elements live at least 7 min x $0.204^{-1} \simeq 34.3$ min. These results compare rather favorably with the theoretical predictions, see e.g. Schmidt et al. 1985.

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Discussion

BECKERS — The Mg I observations which identify the magnetic elements are formed higher in the solar atmosphere than the continuum observations. If magnetic elements are tilted, then this height difference might affect your statistics on the number of magnetic elements inside granules. True?

KOUTCHMY — That is correct. However, the contribution function corresponding to intensities recorded with the UBF at the wavelength we used ($\Delta\lambda = 0.4$ Å from the center of the Mg I b_1 line), has its maximum at a rather small height of 200–300 km, which is smaller than the size of the magnetic elements which we picked up (0.77 arcsec). Additionally, I should mention that these filtergrams were taken practically at the center of the disk.

NORDLUND — Your results are instrument dependent, so you should be careful in interpreting them!

KOUTCHMY — We try to avoid instrumental effects. For example, instead of using white light observations that are polluted by line blocking, we select a segment of true continuum by using a very narrow passband. Also, the results of statistical analyses with large samples are less sensitive to instrumental effects. However, let me point out that the results presented here concern plages; for the quiet Sun the conclusions may not be valid.

TITLE — I am not sure that the line blocking effect is important in our SOUP observations, and whether this can explain the discrepancy in the rms results.

KOUTCHMY — This should be investigated. Concerning the rms results, I should point out that these are clearly affected by errors of statistical origin. The behaviour of the power spectra seems to be more significant: plages give more power at high frequencies and less power at low frequencies than quiet regions. Subtracting the effects of the 5-minute oscillations won't change this conclusion, since these effects are concentrated in the low-frequency range. Finally, our results concern instantaneous rms values computed over the field of view, not over a time sequence (I thank T. Tarbell for pointing this out).